Ciência Rural
ISSN: 0103-8478
cienciarural@mail.ufsm.br
Universidade Federal de Santa Maria
Brasil

Ciência Rural, Santa Maria, v.47: 02, e20160026, 2017 http://dx.doi.org/10.1590/0103-8478cr20160026

ISSNe 1678-4596
SOIL SCIENCE

Fertilizer shanks to promote soil decompaction in the seeding operation

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ABSTRACT: *Intensification of soil compaction process under no-tillage (NT) is motivating the search for alternatives to mitigate soil compaction state. This study evaluated changes in soil physical and hydraulic properties caused by seeder with fertilizer shanks at different depths compared with the double discs lagged seeder, to investigate the possibility of soil decompaction by sowing under NT in southern Brazil. The study was conducted in a clayed Oxisol, for 27 years under NT. Treatments were three planting mechanisms: $S_{0.10m}$: cutting disc combined with shank acting to 0.10m depth; $S_{0.15m}$: cutting disc combined with shank acting to 0.15m depth and, $D_{0.07m}$: double discs lagged acting to 0.07m depth in an experimental randomized block design with four replications. We evaluated the soil mechanical resistance, water infiltration rate, soil bulk density, pore size distribution and unsaturated hydraulic conductivity. Results indicated that the use of seeder with fertilizer shanks acting at 0.15m deep promoted the soil decompaction by the reduction of penetration resistance and increase of porosity and unsaturated hydraulic conductivity. To have significant increase in water infiltration rate the fertilizer shanks of the seeder must be deepened to the lower limit of the compacted surface layer.*
Key words: *soil management, mechanical decompaction, soil structure recovery.*

Haste sulcadora para descompactação do solo na operação de semeadura

RESUMO: *A intensificação do processo de compactação do solo em sistema plantio direto (SPD) motiva a procura por alternativas para atenuação do estado de compactação do solo. Esse trabalho objetiva avaliar modificações em propriedades físico-hídricas do solo originadas por semeadoras equipadas com hastes sulcadoras que atuam em diferentes profundidades, em comparação à semeadora com discos duplos defasados, para investigar a possibilidade de descompactação do solo na operação de semeadura em áreas sob SPD na região Sul do Brasil. O estudo foi realizado em Latossolo Vermelho Distrófico típico, de textura argilosa, há 27 anos sob SPD. Os tratamentos foram três mecanismos de semeadura: $H_{0,10m:}$ disco de corte combinado com haste sulcadora atuando a 0,10m de profundidade; $H_{0,15m}$: disco de corte combinado com haste sulcadora atuando a 0,15m de profundidade; e $D_{0,07m}$: discos duplos defasados atuando a 0,07m de profundidade, em delineamento experimental blocos ao acaso com quatro repetições. Avaliou-se a resistência mecânica à penetração, taxa de infiltração de água no solo, densidade do solo, distribuição do tamanho de poros e condutividade hidráulica do solo não saturado. Os resultados indicaram que a utilização de semeadora com haste sulcadora atuando a 0,15m promove a descompactação do solo através da redução da resistência mecânica do solo à penetração, aumento da porosidade e da condutividade hidráulica. Para que haja aumento significativo da infiltração de água no solo, a haste sulcadora da semeadora deve ser aprofundada até o limite inferior da camada superficial compactada.*
Palavras-chave: *manejo do solo, descompactação mecânica, estrutura do solo.*

INTRODUCTION

No-tillage system (NTS) is defined as a complex of technological processes for agricultural production systems where soil mobilization occurs only in the sowing line, maintenance of soil cover and plant species diversification, through rotation and/or intercropping cultures (DENARDIN et al., 2011). However, of the 32 million hectares managed under no-tillage in Brazil, no more than 2.7 million hectares are cultivated in the winter season, so with potential to meet the crop rotation precepts and soil coverage of the management system (DIAS, 2014). In addition, the monoculture of soybean / fallow and succession such as soybean / winter maize or soybean / millet, which occupy the vast majority of areas managed under no-tillage in Brazil, are not a crop rotation system, required as one of the precepts of the NTS (DIAS, 2014). Associated with the partial implementation of the NTS precepts the use of seeders devoid of fertilizer shanks with deposition of fertilizer on the surface or in the surface layer of soil with intensive grazing and increasing agricultural machinery traffic frequency has led to the formation of a layer of more compacted soil, between 0.07 and 0.15m, which can hinder or even prevent root growth (SUZUKI et al., 2008; DRESCHER et al., 2011). In this layer the compaction rate caused by the

Received 01.12.16 Approved 10.17.16 Returned by the author 12.05.16
CR-2016-0026.R2

successive pressure applied to the ground is greater than the decompression rate promoted by agents that act more effectively in soil surface, thus implying a progressive increase in the degree of compaction.

Soil decompaction favors the initial development of cultivated plant roots, its growth to deeper layers and subsequent formation of biopores, which facilitate air and water flows in the soil (BRADY & WEIL, 2013). As a strategy to decompact the soil, farmers make mechanical soil chiseling. As an immediate effect of this practice the compacted layer is broken and has an increase of surface roughness, with benefits to soil water infiltration rate, reduction of the bulk density and increasing porosity.

However, chiseling is an energy-intensive operation, requires investment to purchase ripper and implies changes in the management system (CHAMEN, 2015), in contrast to the provision of minimum soil mobilization implicit in the NTS. In addition, the change in soil properties promoted by soil chiseling has presented short duration (DRESCHER et al., 2012; SILVA et al., 2012), often less than one year (ALVAREZ, et al., 2009).

As a result, soil chiseling may not be the best alternative of soil mechanical decompaction or to prevent it reaches critical levels of compaction. This is because the ordinary use of the chisel plowing may leave the soil more susceptible to a subsequent more intense compaction (CANARACHE et al., 2000), since the increase in time without revolving the soil under NT alters the bonding strength of the soil aggregated particles, increasing the strength of the structure to forces applied to the soil (REICHERT et al., 2010). Thus, there is need to find alternative solutions for soil decompaction.

Use of seeders equipped with furrow openers type fertilizer shanks, which act in sequence to the cutting discs is an option to be tested for soil decompaction in the row. This practice enables the decompaction located only in the vicinity of the site of deposition of the seed, which can be sufficient to improve the physical properties of soil, eliminating all mechanical chisel plowing for whole soil of roots growing layer.

However, the vast majority of seeders seed drills, have angle and dimensions that limit their action to depths greater than 0.10m. Fertilizer shanks with narrow tips, which equip most seeders used in no-tillage have limited capacity to promote the breakdown of cross-sectional area of the groove and mobilize soil (HEMMAT & ADAMCHUK, 2008), restricting their ability to decompress the ground managed under NTS. For seeders equipped with furrow openers at different depths of action, little is known about the changes in physical and hydraulic properties of the soil. Thus, the present study aimed to evaluate the changes in physical and hydraulic properties of the soil with seeder equipped with fertilizer shanks acting at different depths compared to seeder with double discs lagged in order to investigate the possibility of reducing the state of soil compaction by sowing operation in areas managed under no-tillage system in southern Brazil.

MATERIALS AND METHODS

The study was conducted in the experimental field of the National Wheat Research Center - Embrapa Trigo, located in the municipality of Coxilha - RS, in a typical dystrophic red Latossol (EMBRAPA, 2013), clayey, with an average of 55% clay, 23 % silt and 22% sand, at soil surface. The climate, according to Köppen classification, is Cfa - humid subtropical climate with rainfall well distributed throughout the year.

The study was conducted in the summer field season of 2012/2013 using an experiment established in 2009 in an area used for grain production managed under NTS for 27 years. The experiment crop sequence was: corn (2009/2010), wheat (2010), soybean (2010/2011), rye (2011), maize (2011/2012), wheat (2012) and soybean (2012/2013). The winter crops were sown with dual disc lagged with spacing of 0.17m, while the summer crops were sown with three compositions sowing mechanisms, which constituted the treatments of this study:

$S_{0.10m}$: cutting disc combined with shank acting to 0.10m deep;

$S_{0.15m}$: cutting disc combined with shank acting to 0.15m deep; and

$D_{0.07m}$: double discs lagged acting to 0.07m deep.

The shank used in no-till seeder has adjustable length depending on the desired depth of operation, up to 0.25m depth; thickness of 0.01m, width 0.06m and angle of attack to the ground equal 90º. The shank tip is incorporated into the body of the shank also having 0.01m in thickness, with the front of the shank beveled and the angle of attack of 22.5º. The spacing between the shanks (sowing lines) was 0.35m for the soybean crop and 0.70m for the corn crop. The experiment was conducted in experimental design of randomized blocks with four replications, totaling thus 12 experimental units of 14.4m^2 (8m x 1.8m).

In December 2012 and April 2013 (beginning and end of the soybean crop cycle, respectively), the soil mechanical resistance to penetration (PR, MPa) was measured in the field, using a georeferenced penetrometer PNT-2000, according to ASAE standards S 313.3 (ASABE, 2006). The rod, with conical tip of 30º and conical area of 129mm^2, was inserted into the ground to penetration speed of approximately 2m min^{-1}, and PR data recorded every 0.01m to 0.40m depth. Measurements were carried out on the seeding line and 0.05, 0.10 and 0.20m to the left and right, between the lines of sowing. At the time of PR measurements soil samples were collected to determine the gravimetric water content, 0.03, 0.10, 0.15, 0.20, 0.30 and 0.40m depth in three points of each experimental block.

The water infiltration rate in the soil was measured in March 2013, on the soybean seeding line, using infiltrometer of concentric rings with diameters of 0.20m and 0.40m for the inner and outer ring, respectively, both inserted in the soil to a depth of 0.15m, according to the methodology described by EMBRAPA (2011). A steady state of infiltration rate was assumed (SIR mm h^{-1}) with the value of final reading (at 2h) because at that time there was little variation in the rate of infiltration.

Soil samples with preserved structure were collected in May 2013, using stainless steel rings measuring 0.04m high and 0,055m in diameter, in soybean planting row in layers from 0 to 0.07m, 0, 07 to 0.15m and 0.15 to 0.25m. Samples were saturated in a tray, in which the high of water was gradually increased to the upper edge of the rings, for 48 hours, weighed, and carried to the sand column (REINERT & REICHERT, 2006) for application of tensions (Ψ, kPa) of 1, 6 and 10kPa, and Richards chambers for the application of Ψ of 33 and 100kPa (KLUTE, 1986). In each Ψ, the samples were weighed to determine the volumetric water content (θ, cm^3 cm^{-3}). In Ψ of 500 and 1500kPa, the water content was estimated by dew point psychrometer - WP4, as described by KLEIN et al. (2006). The data ψ and θ of each sample was adjusted by the VAN GENUCHTEN (1980) model according to the equation:

$$\theta = \theta_r + (\theta_s - \theta_r)\left[1 + (\alpha\psi)^n\right]^{-m} \qquad (1)$$

On what: θ, θ_r e θ_s are the volumetric, residual and saturation water content, respectively, expressed in cm^3 cm^{-3}; ψ is water tension in soil, expressed in kPa; α (kPa^{-1}), n and m are empirical coefficients of the equation.

The θs parameter was considered equal to the total porosity; the parameter m is restricted to the condition m = 1-1/n, in order to estimate the unsaturated hydraulic conductivity, by criteria suggested by MUALEM (1976); The θr, α and n parameters were estimated by regression analysis, using the proc NLIN procedure of SAS 9.2 (SAS INSTITUTE INC., 2010).

The hydraulic conductivity of the unsaturated soil (K) was estimated by the theoretical model of Van Genuchten-Mualen as described in JONG VAN LIER et al. (2009):

$$K = K_s S_e^{\gamma}\left[1 - \left(1 - S_e^{\frac{1}{m}}\right)^m\right]^2 \qquad (2)$$

On what: S_e is the effective saturation (θ - θr) / (θs - θr); γ = 0.5; Ks is the hydraulic conductivity of saturated soil (mm h^{-1}) measured in constant head permeameter (LIBARDI, 2012); and m is obtained from the equation (1).

The total porosity (Tp, m^3 m^{-3}), microporosity (Mi, m^3 m^{-3}), macroporosity (Ma, m^3 m^{-3}) and bulk density (BD, Mg m^{-3}) were determined by the method described in EMBRAPA (2011). Prior to analysis of variance, the variables were submitted to Lilliefors tests for normality and Cochran for homogeneity of variance. It was detected abnormal distribution of SIR, which was subjected to logarithmic transformation. When the analysis of variance was significant, the treatments were compared by Tukey test. All these tests were performed in statistical software Assistat 7.7 beta (SILVA, 2015) and evaluated to 5% error probability.

RESULTS AND DISCUSSION

The use of fertilizer shanks ($S_{0.10m}$ e $S_{0.15m}$) did not modify the BD compared to using only lagged Dual Discs ($D_{0.07m}$), for all the evaluated soil layer (Table 1). In the layer of 0 to 0.07m there were also no differences for Tp, Ma and Mi between treatments. This is because that the three seeding line preparation mechanisms ($S_{0.10m}$, $S_{0.15m}$ e $D_{0.07m}$) mobilized the soil layer from 0 to 0.07m. Furthermore, the higher root and the organic matter concentration at the soil surface promoted a greater biological activity and also intensity of wetting and drying cycles (BAVOSO et al., 2012), which contributed to soil decompaction.

Unlike, in the layer from 0.07 to 0.15m, the soil mobilization promoted by $S_{0.15m}$ increased Pt and Ma because $D_{0.07m}$ mechanism did not cause disturbance at this depth, and the soil disturbance promoted by $S_{0.10m}$ was not enough to promote decompaction higher than promoted by $D_{0.07m}$. This indicated that, in clayey Oxisol , compacted soil layer which is located between 0.07 and 0.15m, as seen

Table 1 - Changes in soil bulk density, total porosity, macro and microporosity by seeding mechanisms, in layers from 0 to 0.07m, 0.07 to 0.15m and 0.15 to 0.25m.

Soil properties	Soil layer (m)	------------------------------Seeder mechanisms------------------------------			CV (%)
		$D_{0.07m}$	$S_{0.10m}$	$S_{0.15m}$	
Bulk density ($Mg\ m^{-3}$)	0 a 0.07	1.13^{ns}	1.14	1.11	5.9
	0.07 a 0.15	1.46^{ns}	1.42	1.30	6.5
	0.15 a 0.25	1.36^{ns}	1.32	1.28	4.3
Total porosity ($m^3\ m^{-3}$)	0 a 0.07	0.61^{ns}	0.60	0.61	4.2
	0.07 a 0.15	$0.48\ ^{*}$b	0.48 b	0.52 a	4.4
	0.15 a 0.25	0.51^{ns}	0.52	0.52	4.4
Microporosity ($m^3\ m^{-3}$)	0 a 0.07	0.37^{ns}	0.23	0.39	6.2
	0.07 a 0.15	0.40^{ns}	0.40	0.42	3.6
	0.15 a 0.25	0.44^{ns}	0.45	0.46	5.9
Macroporosity ($m^3\ m^{-3}$)	0 a 0.07	0.23^{ns}	0.37	0.22	19.2
	0.07 a 0.15	$0.08\ ^{*}$b	0.08 b	0.10 a	13.4
	0.15 a 0.25	0.07^{ns}	0.07	0.07	30.1

*Values followed by the same letter on the line do not differ by Tukey test at 5% probability. $S_{0.10\ m}$: cutting discs combined with fertilizer shanks acting to 0.10m depth;
$S_{0.15m}$: cutting discs combined with fertilizer shanks acting to 0.15m depth;
$D_{0.07m}$: double discs lagged acting to 0.07m depth.

in several areas managed under no-tillage (SUZUKI et al, 2008;. DRESCHER et al., 2011), the deepening of fertilizer shanks up to 0.15m is required when the sowing operation has decompaction as its purpose.

The PR was lower in the beginning of soybean cycle (Figure 1a); although, water content in the superficial layers of the soil was lower than at the end of the cultivation cycle. Both the beginning and end of the soybean cycle, figures 1a and 1b, shows that the PR along the sowing line did not exceed 2.0MPa, value often considered critical for root development of crops (COLLARES et al., 2006; REICHERT et al., 2009), up to 0.20m deep where sowing was done with $S_{0.15m}$. Furthermore, PR was higher than 3.0MPa in the layer between 0.10 and 0.15m in places where seeding was carried out with $D_{0.07m}$. This result allowed to infer that when fertilizer shank used in the sowing operation was set to reach 0.15m depth, it was efficient to break the cross-section of the groove area, decompacting the soil and forming a soil profile with less resistance to mechanical penetration along the seeding line.

Seeding mechanisms have also changed the estimated K (equation 2) at different water tensions (10, 33, 100, 500 and 1000kPa), in the layer 0 to 0.07 and 0.07 to 0.15m (Table 2). In the layer of 0 to 0.07m, both $S_{0.10m}$ and $S_{0.15m}$ promoted increased in K compared to $D_{0.07m}$. However, in the layer 0.07 to 0.15m, as similar to what was observed for Pt, Ma and PR, only $S_{0.15m}$ was efficient to increase K. The K reflects the physical condition of the soil as structure, porosity and presence of compacted layers, thus the benefits verified by the use of fertilizer shank $S_{0.15m}$ on the distribution of pore size in no-tillage managed areas increased soil hydraulic conductivity at different water tensions, benefiting the soil water flows.

The increase in K by use of $S_{0.15\ m}$ reflected in increased of steady infiltration rate at 2h, which was two and a half times higher where sowing was carried out with $S_{0.15m}$ in relation to the use of $S_{0.10\ m}$ or $D_{0.07\ m}$ (Figure 2a). Consequently, the total infiltrated water, at the end of 0.5, 1 and 2 hours of evaluation, was always greater in the treatment $S_{0.15m}$ as compared to treatment $S_{0.10\ m}$ or $D_{0.07\ m}$ (Figure 2b). These results corroborated what VIZZOTTO (2014) reported, that after 180 minutes of infiltration was observed increments of 89.2% for infiltration rate and 69% for cumulative infiltration when fertilizer shanks was used as compared where only discs were used. However, in this study, the depth of shank action had more significant effect to increase water infiltration into the soil than the type of mechanism itself.

Compared to treatments $S_{0.10m}$ and $D_{0.07m}$, the treatment $S_{0.15m}$ reduced PR and increased Tp, Ma and K in greater depth, and increased SIR at 2h and accumulated infiltration into the soil. From these results, it appears that the sowing operation can also perform the function of decompacting the topsoil, since the fertilizer shanks can operate to a depth of 0.15m. This suggested that tillage with fertilizer shanks in seeders can replace the tillage with tillers, when the objective is to decompact the topsoil.

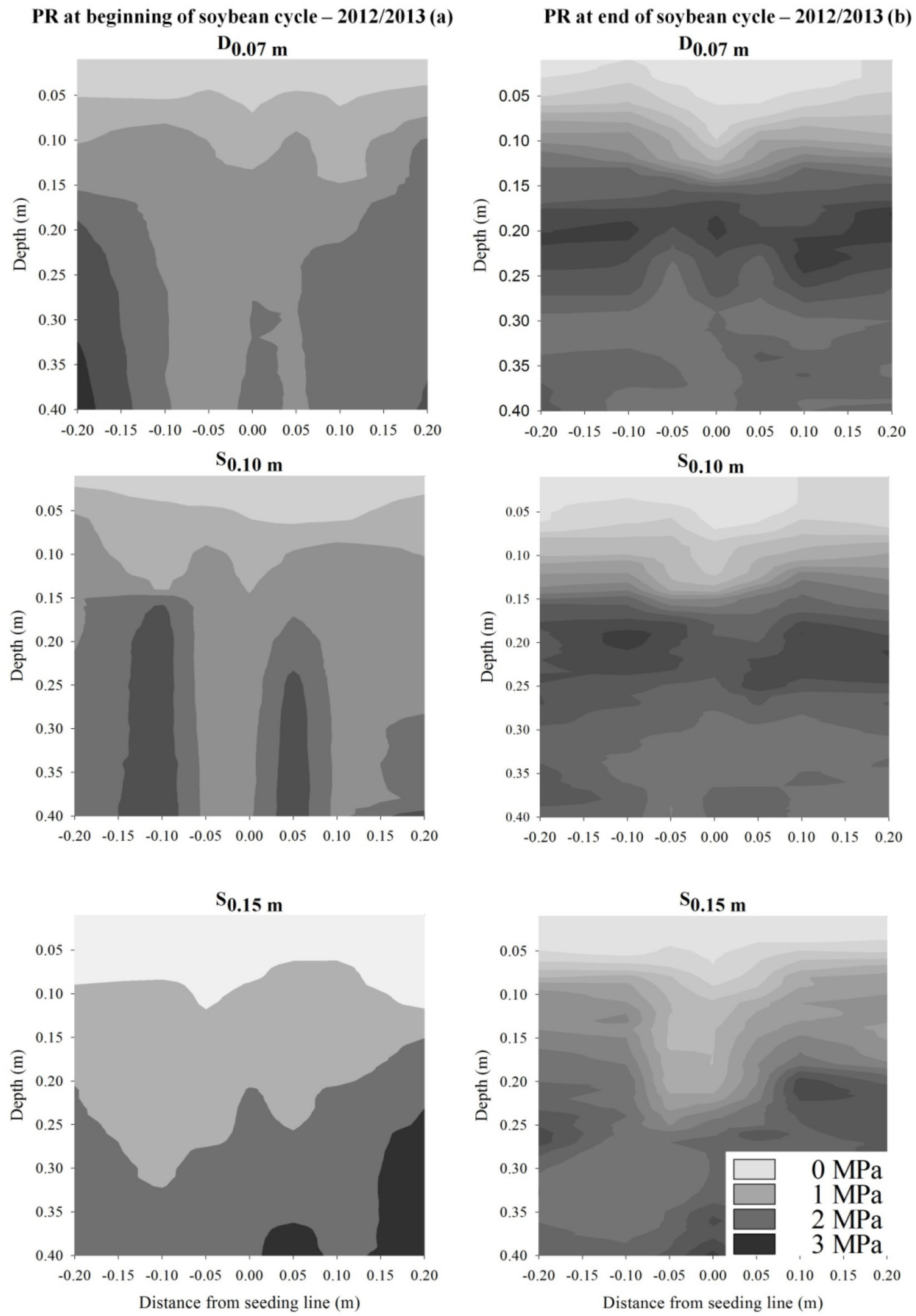

Figure 1 - Soil resistance to mechanical penetration (MPa) evaluated 20 days after sowing (a) and at the end of the soybean cycle (b). $S_{0.10m}$: cutting discs combined with fertilizer shanks acting to 0.10m depth; $S_{0.15m}$: cutting discs combined with fertilizer shanks acting to 0.15m depth; $D_{0.07m}$: double discs lagged acting to 0.07m depth. Soil water content from 0 to 0.4m depth ranging from 0.268 to 0.32g g^{-1}, after sowing and 0.28 to 0.31g g^{-1} at the end of soybean cycle.

Table 2 - Changes in the hydraulic conductivity of the unsaturated soil (K) by seeding mechanisms in layers 0 to 0.07m. 0.07 to 0.15m and 0.15 to 0.25m.

Seeder mechanisms	K ($mm\ h^{-1}$)				
	10 kPa	33 kPa	100 kPa	500 kPa	1000 kPa
0 a 0.07m					
$D_{0.07m}$	49.13 *b	39.48 *b	33.36 *b	7.29 *b	5.66 *b
$S_{0.10m}$	297.14 a	261.59 a	217.18 a	54.53 a	42.71 a
$S_{0.15m}$	242.75 a	202.90 ab	171.52 a	37.30 a	29.16 a
CV (%)	79.1	80.5	80.1	92.9	93.2
0.07 a 0.15m					
$D_{0.07m}$	5.38 *b	4.92 *b	4.36 *b	1.35 *ab	1.08 *ab
$S_{0.10m}$	1.95 b	1.78 b	1.60 b	0.49 b	0.39 b
$S_{0.15m}$	38.31 a	32.64 a	28.43 a	6.21 a	4.94 a
CV (%)	140.3	142.5	140.7	135.8	135.9
0.15 a 0.25m					
$D_{0.07m}$	3.40^{ns}	3.02^{ns}	2.60^{ns}	0.75^{ns}	0.59^{ns}
$S_{0.10m}$	2.53	2.25	1.95	0.53	0.42
$S_{0.15m}$	9.22	7.31	6.63	1.48	1.17
CV (%)	102.1	94.4	97.5	74.3	74.2

*Values followed by the same letter on the column do not differ by Tukey test at 5% probability.
$S_{0.10m}$: cutting discs combined with fertilizer shanks acting to 0.10m depth;
$S_{0.15m}$: cutting discs combined with fertilizer shanks acting to 0.15m depth;
$D_{0.07m}$: double discs lagged acting to 0.07m depth.

CONCLUSION

The use of seeders equipped with fertilizer shanks with action depth of 0.15m, promotes decompaction of the top soil under no-tillage, reducing soil mechanical resistance to penetration and increasing porosity and hydraulic conductivity.

To have a significant increase in water infiltration into the soil, the fertilizer shank of the seeder must be deepened to the lower limit of the compacted surface layer.

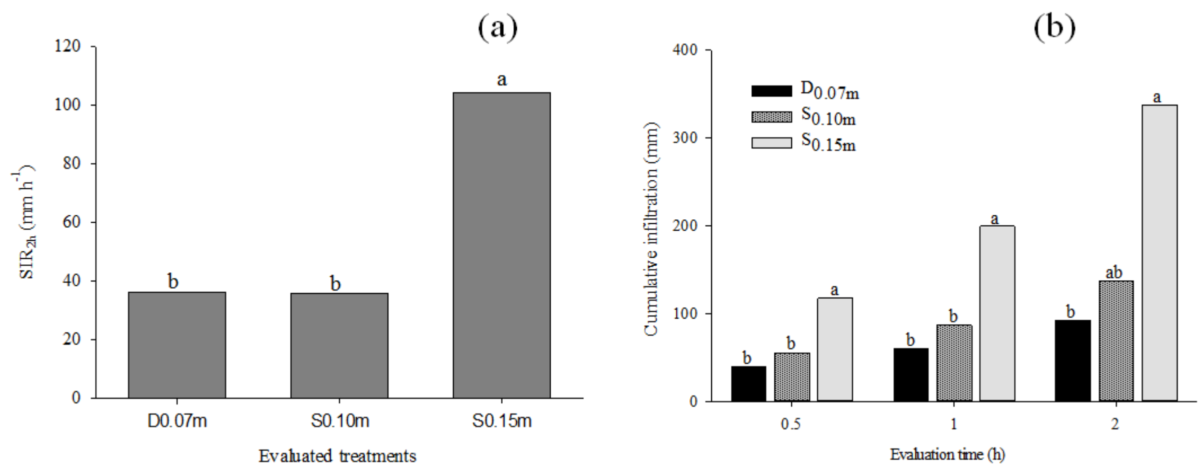

Figure 2 - Water infiltration rate into the soil at the end of two hours evaluation (SIR at 2h) (a) and cumulative infiltration at the end of 0.5, 1 and 2 hours of measurements (b). *Columns with same letter (Figure a) and same letter at the same time evaluation (Figure b) did not differ statistically by the Tukey test at 5% probability. $S_{0.10m}$: cutting discs combined with fertilizer shanks acting to 0.10m depth; $S_{0.15m}$: cutting discs combined with fertilizer shanks acting to 0.15m depth; $D_{0.07m}$: double discs lagged acting to 0.07m depth.

ACKNOWLEDGEMENTS

We would like to thank the financial support of the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq/Brasil) and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES)

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